RESEARCH REPORTS
An Overview

1999 once again showed a significant increase in the scope and strength of the research projects in the laboratory. The number of projects increased to 310 from 293, 255, and 239 in previous years. There continues to be increased collaborative research between in-house research staff and external users, some of which is supported by the NHMFL In-House Research program (see Chapter 3). Reports sponsored in this manner are denoted by IHRP in the text.

The research of the laboratory is broadly distributed across the disciplines, with the largest number of projects being superconductivity (43), semiconductors (37), magnetism and magnetic materials (36), magnetic resonance techniques (35), biology (34), chemistry (24), molecular conductors (24) and heavy fermions (22).

We highlight a few topics from several of the areas of research as typical of the overall research program. Other projects of comparable importance could have been chosen as one can see from this report.

Biology

Houpt, T. A. and his colleagues (page 19) have discovered both behavioral and neuronal effects on rats exposed to a 9.4 T magnetic field for 30 minutes. This discovery will permit the development of rats as an animal model for high field exposure for humans in magnetic resonance imagers. Today, MRI technology is pushing to higher and higher fields, but with little known about sensory or physiological effects of high field exposure. Through an animal model it will be possible to characterize the effects of field strength and exposure time.

This group has documented the behavioral effects with a conditioned taste aversion, a sensitive index of visceral malaise suggesting that high magnetic fields may be an adversive stimulus to the rat. The same exposure also induces a specific and significant c-Fos immunoreactivity, quantified following brain sectioning of the rats. These behavioral and neural effects are similar to those induced by motion sickness, and they are also consistent with the reports of vertigo and nausea in humans during 4 T MRI studies.

Chemistry

Photosynthesis: High-Field EMR Studies of Photosynthetic Pigment Radicals Beyond the Limits of Superconducting Magnets. Photosynthesis is one of the more important energy transfer procedures on earth. Chlorophyll and carotenoid molecules are essential to the primary processes of photosynthesis. Their radical forms, which are created *in vivo* as part of the photosynthetic light reaction (intermediate states) or as byproducts in photochemistry, have been studied for many years to learn more details regarding the molecular mechanisms underlying this fundamental biological process. Electron magnetic resonance is well suited to investigate these radicals. The limitations posed on EMR spectroscopy at traditional field/frequency combinations—in particular the lack of spectral resolution for the small g-factor anisotropy of these radicals—have recently been overcome. Using high field EPR at fields of up to 24 T available in the high-homogeneity Keck magnet at the NHMFL the following results were obtained:

1. The full g-anisotropy of the primary donor radical cation (special pair chlorophyll dimer) in bacterial photosynthesis has been determined both for

bacteriochlorophyll (BChl) and BChl b containing species, and electronic structural information can be obtained that is not otherwise available (Bratt, P. *et al.* page 12).

2. The axial g-anisotropy was determined for the primary donor radical cation of the very symmetric chlorophyll dimer in *Heliobacterium chlorum* (Bratt, P. *et al.* page 12).
3. No indication of g-strain was observed in any of the biological samples indicating the possibility of even higher resolution at higher field/frequency combinations. This should allow the resolution of the full anisotropic g-tensor for the *Heliobacterium chlorum* primary donor (Bratt, P. *et al.* and Konovalova, T. A. *et al.* page 35).
4. The first example of a well-resolved EMR spectrum of a *canthaxanthin* (carotenoid) radical cation *in vitro* was observed at fields up to 24 T. Only an axial g-tensor could be resolved. This is expected from theoretical calculations, however, and allows the unambiguous distinction of carotenoid radical cations from other C-H containing radicals with different symmetry (Konovalova, T. A. *et al.* page 35).

These results demonstrate the potential of high field/high frequency EMR (HF-EMR) at magnetic fields well beyond those attainable with current superconducting magnet technology. HF-EMR will open the path for more detailed spectroscopic analysis of the electronic structure of these radicals employing high field ENDOR techniques. These experiments document the need for high homogeneity magnetic fields of up to 36 T.

Geochemistry

Basalts at the Earth's surface exhibit a large range in isotopic compositions. One of the long outstanding questions in mantle geochemistry is whether the isotopic heterogeneities observed in basalts, especially enrichments, are associated with mineralogical differences in their source (i.e., the Earth's mantle). It is argued that the Earth's mantle is like a "marble cake" or "plum pudding," whereby the "plums" or the thin layers consist of pyroxenite and the bulk of the mantle consist of peridotite. The new information on compositionally dependent partitioning of trace elements (reported by Salters, V. J. M. *et al.* page 50) allows researchers to distinguish between melts from peridotite and pyroxenite. The Group produced additional isotopic compositions on Hawaiian basalts thereby producing the most complete dataset on any suite of basalts. The comprehensive Hawaiian dataset, which now includes U-Th, Hf and Nd isotopic compositions and trace element concentrations, interpreted in light of the compositionally dependent partition coefficients, rules out the existence of a marble cake mantle. Or, melts derived from pyroxenite have not significantly contributed to the enriched basalts at Hawaii, the Earth's largest hot spot. This interpretation (Stracke, Salters and Sims) has been reported in the inaugural issue of G^3 (*Geochemistry, Geophysics and Geosystems*). G^3 is a new electronic journal in the Earth Sciences founded with support of Harvard University, Scripps Institution of Oceanography, Lamont-Doherty Earth Observatory of Columbia University, Florida State University, and the NHMFL.

Superconductivity—Basic

While it has been more than a dozen years since the first discoveries of high temperature superconductors, the details of the pairing mechanism, the role of magnetism and magnetic correlations, and the connection of the pseudogap above T_c to the superconductivity, as well as many other questions, remain unsolved. The vortex phase diagram, which depends on the microscopic behavior, has still not been fully mapped. Recent work at high magnetic fields, used to suppress T_c, has allowed low temperature studies of the normal state properties, particularly spin fluctuations, and thrown new light on some of these issues.

Julien *et al*. (page 63) investigated the recently discovered coexistence of superconductivity and a "cluster spin glass" state in $La_{1.94}Sr_{0.06}CuO_4$ by ^{139}La NMR T_1 measurements up to 23.2 T. The conclusion from these experiments is that the Cu^{2+} spin fluctuations in the CuO_2 planes continuously slow down and spin freezing coexists with superconductivity below 1 to 2 K. Charge localization was recently found at high fields in these compounds, and a relationship probably exists between these phenomena.

Theoretical studies of Dorsey and Kwon (page 60) focussed on the concept that the pseudogap region has local superconducting order, but that phase fluctuations destroy long range order. In their model, 2-D Kosterlitz-Thouless vortex pair unbinding transition, the fluctuations change dramatically as the superconducting transition is approached, leading to broadening of the quasipartical spectral density function and a pseudogap feature. These results reflect the photoemission and NMR experimental observations.

From transport measurements in $Bi_2Sr_{2-x}La_xCuO_{2-\delta}$, x=0.23 to 0.84, at fields to 60 T in the normal state, Ono *et al*. (page 66) have found that the metal insulator transition (MI) shows a gradual onset with x, and that metallic behavior is observed in underdoped samples. Thus the MI transition lies in the underdoped region. This is in contrast to previously studied $La_{2-x}Sr_xO_4$ and the electron doped $Pr_{2-x}Ce_xCuO_{4-\delta}$ in which the MI transition occurs at exactly optimum doping. This indicates that the crossover is not universally at optimum doping, as had been previously proposed.

The vortex phase diagram of high T_c superconductors is very complex, and there are still many unanswered questions of the detailed behavior, which is important for the basic physics and for technological applications. Kwok *et al*. (page 64) compared samples with columnar defects produced by heavy ion irradiation with pieces of the same sample with only point defects by transport measurements to 18 T. A dramatic shift of the upper critical point of the liquid to glass transition, from 9 to 11 T, was observed for the first time in this work. This is interpreted as due to the reduction of transverse wandering and entanglement of the vortices in the samples with columnar defects, particularly at high fields, indicating that entanglement is a key feature of the high field disordered state.

There has been considerable controversy recently over the role and the behavior of the pseudogap just above T_c, presumably due to strong electron electron correlations. Previous NMR studies have shown the pseudogap field (and thus T_c) independent in underdoped materials, with a question remaining as to the behavior of optimally doped materials. Zheng, G. Q. *et al.* (page 70) have studied the ^{63}Cu NMR in $TlSr_2CaCu_2O_7$ in the slightly overdoped regime and find a very strong field dependence of the Knight shift and $1/T_1$, in contrast to the underdoped materials, that follows a scaling relation consistent with the Cooper pair density fluctuations and d-wave symmetry. This behavior of the psuedogap with doping should help resolve some of the previous controversy and provide enlightenment on the role and nature of the pseudogap.

Superconductivity Applied

Influence of Thermal Cycling on Mechanical Properties $Bi_2Sr_2CaCu_2O_x$ Superconductors. One of the limitations for the application of high-T_c cuprate superconductors is their poor mechanical strength. The strength of the powder-in-tube $Bi_2Sr_2CaCu_2O_x$/Ag conductor composites is a complex interplay between the soft silver sheath and the brittle oxide core. The use of silver alloys instead of pure silver significantly enhances the mechanical strength of the conductor. The silver alloys, however, reduce J_c performance by 20 to 30 percent. This is due to the thermal expansion mismatch between the outer silver alloy sheath and the inner oxide core. The goal of the studies by Viouchkov, Y. *et al.* (page 76) is to understand and model the mechanical behavior of powder-in-tube superconducting composite tapes. The essential data that goes as input in the models is obtained through a variety of stress-strain-I_c measurements over a wide range of temperatures. The inferior I_c performance of silver alloy sheathed conductors, compared to that of the silver sheathed conductors, is explained as due to the hard silver alloy putting the oxide core in compression when cooling.

Quantum Solids

Achieving an understanding of the magnetization and growth kinetics in quantum solid has been a major challenge. Recent NMR and thermodynamic experiments at ultra-low temperatures and high magnetic fields (high B/T) on nanoclusters of ^{3}He in a ^{4}He matrix have shown that the magnetic susceptibility growth is continuous with a quite small Weiss theta. Possible ordering is now under study. Nanoclusters, formed on cooling ^{3}He = ^{4}He mixtures, are observed by following the pressure and the magnetic susceptibility (Adams, D. *et al.* page 78).

Of particular significance is the recent accurate measurement of the nuclear spin-spin relaxation of ^{3}He in well-defined 2D lattices at high magnetic fields in Parks, C. *et al*. (page 79). These measurements provide a direct measurement of the quantum tunneling rates in 2D and offer new insights into the frustration of nuclear magnetic interactions in the quantum solids. In particular, a temperature independent relaxation rate has been observed at low temperatures and attributed to relaxation induced via a quantum exchange motion. At high temperatures one observes an activated relaxation from which one can determine the 2D binding energies.

Kondo High Field

The magnetic parentage of the electronic properties of heavy fermion materials makes them interesting candidates for experimental investigations in high magnetic fields. Heavy fermion superconductivity continues to be a rare occurrence, the conditions for which remain a complete mystery. There are several heavy fermion superconducting materials where crystal of very high perfection have been synthesized, enabling detailed Fermi surface investigations. UPt_3 is one of the best studied materials in this regard, yet it continues to yield surprises. In the vicinity of applied fields in the basal plane of 20 T, UPt_3 undergoes what is described as a metamagnetic transition. Great interest attaches to the question as to what happens to the electronic structure at this transition, and whether the Fermi surface volume remains constant through it. Experiments by Feller, J. *et al.* (page 84) at the NHMFL using high resolution ultrasonics on very high quality crystals of UPt_3 have discovered a new quantum acoustic oscillation corresponding to a mass of 31.4 m_e above this transition. This finding is providing a first hint as to possible restructuring of the Fermi surface in the metamagnetic phase.

Molecular Conductors

Two of the most important aspects of molecular conducting systems are their anisotropy and their large variety of possible ground states. Access to more sophisticated measurement methods, primarily in high magnetic fields, is leading both to new high field ground states, and more detailed information about existing, but controversial systems. In this report there are several general areas where there has been exciting, and even controversial, progress.

One of the most complex organic systems is the quasi-two-dimensional material α-(BEDT-TTF)$_2$-KHg(SCN)$_4$, along with its isostructural family where Tl, Rb, or NH_4 is substituted for K. Over the last decade there has been intense experimental interest in these materials due to highly novel aspects of their physical properties below about 12 K, and in fields up to 50 T. Here a highly unusual ground state is found. In this report, there have been significant advances in understanding the nature of this system. Although initially thought to be a spin density wave (SDW) ground state, some workers are promoting a more complex, perhaps charge density wave (CDW) ground state (Harrison, N. *et al*. page 102), or mixed SDW + CDW phase and/or sub-phases that involve both Pauli and orbital mechanisms (Qualls, J. *et al*. page 108). Information concerning the nature of the quantum oscillations in tilted, pulsed magnetic fields has also been obtained. In one study consistency is obtained for the case of the proposed very novel quantum Hall effect in these systems (Honold, M. *et al*. page 103). In another study the splitting of the quantum oscillation wave forms is found to arise from a mechanism that is at odds with the standard understanding of such effects in low dimensional metals (Qualls, J. *et al*. page 107).

Significant progress was made in the computational aspects of α-$(BEDT\text{-}TTF)_2KHg(SCN)_4$ in very high magnetic fields (of order 250 T). For the first time the Hofstadter problem was coupled with the Lifshitz-Kosevich (LK) analysis for the magnetic field and temperature dependence of the magnetization and has been used with realistic band parameters (Han, S. Y. *et al*. page 101). This allowed the determination of effective masses of both fundamental and magnetic breakdown orbits. When spin was introduced into the Hamiltonian, additional parameters of the LK treatment could be determined, and new orbital frequencies were predicted for high spin values. Remarkable agreement of the computed and experimentally determined parameters for this material was obtained.

Another area where new information is coming to our attention from otherwise well-studied materials involves superconductivity in the "kappa" phase materials. Here several very new aspects of these materials have been reported. Based on in-plane high frequency measurements using a novel tunnel diode oscillator (TDO) method with high angular precision, a Fulde-Ferrell-Larkin-Ovchinnikov (FFLO) state is proposed (Symington, J. A. *et al*. page 112) for the organic superconductor κ-$(BEDT\text{-}TTF)_2Cu(NCS)_2$ From these measurements a FFLO sub-phase within the superconducting state is described between 15 and 30 T below 6 K. In a separate investigation of the same material (Hill, S. *et al*. page 103), where very high precision magnetization measurements were carried out as a function of angle, no evidence was found for any unusual sub-phase structure. Rather, vortex dynamics behavior associated with melting and irreversibility lines in the superconducting phase were observed. In a third study of the same system (Mielke, C. H. *et al*. page 105), the in-plane critical field was investigated vs. azimuthal angle with high precision in pulsed magnetic fields. Only two-fold asymmetry was observed, unlike that expected for d-wave paring where four nodes (and symmetry) should appear in the gap. Clearly, more work is needed to explore this highly unusual anisotropic superconducting system. (See also Coffey, T. *et al.* page 97, who used the TDO method above to investigate this material in pulsed fields).

Unique by the nature of the method is the use of phase-locked mm wave spectroscopy to explore the physical properties of low dimensional systems, and this is one predominant theme in the present report. Superconductivity was studied in κ-$(BEDT\text{-}TTF)_2Cu(NCS)_2$ (see discussion above) by two different groups. Angular dependent studies at 71 GHz were reported vs. magnetic field at 1.4 K (Edwards, R. S. *et al*. page 98). The method was sensitive to the one-dimensional Fermi surface topology, where two warping components could be observed (see also Ardavan, A. *et al*. page 95 and Symington, J. A. *et al*. page 113 for mm wave studies in other BEDT-TTF materials). In another study (Mola, M. *et al*. page 106), Josephson plasma resonance (JPR), which is a specific phenomena associated with highly anisotropic type II superconductors, was measured vs. field for 76 and 111 GHz. Here significant differences in the JPR were reported with respect to similar phenomena in high T_c materials. Finally, high field EPR measurements on $Li(2,5\text{-}DMDCNQI)_2$ at 12 T and 330 GHz reported that a linewidth is only limited by the magnet homogenity (Krzystek, J. *et al*. page 104). This work shows that the mm wave methods can extend EPR studies well above the limit of traditional X-band methods with excellent precision.

Detailed Fermiology studies were carried out with angular dependent transport and magnetization probes on a variety of novel low dimensional systems, including the charge density wave system $NbSe_3$ (Harrison, N. *et al*. page 102) , the purely organic anion-cation system β''-$(BEDT\text{-}TTF)_2SF_5CH_2CF_2SO_3$ (Wosnitza, J. *et al*. page 114), and the strictly closed-orbit material κ-$(BEDT\text{-}TTF)_2I_3$ (Wosnitza, J. *et al*. page 115). Here high precision measurements of effective masses, Fermi surface topologies, and tests of metals physics models have been completed.

Finally, a relatively new area, involving polymer physics was initiated by the Seoul National University collaboration, Suh, D. S. *et al*., sponsored through KOSEF. In the first study (Park, Y. W. *et al.* page 106) polyacetylene doped with ClO_4 was observed to become metallic, and its magnetotransport characteristics were measured. In a second investigation, magnetotransport was studied in S-type (Suh, D. S. *et al*. page 110) and R-type (Suh, D. S. *et al*. page 111) helicities of iodine doped polyacetylene. Here important differences were observed in the properties for the two helicities, and models were proposed to explain both cases.

Semiconductors

The phase diagram of the two-dimensional electron gas in a magnetic field continues to be a source of fascinating new physics. Among the most interesting recent developments in this field has been the discovery that at high filling fractions in which the highest occupied Landau level is half filled ν = 9/2, 11/2, 13/2, 15/2, etc.) the transport properties of the two-dimensional electron gas become highly anisotropic. This anisotropy, characterized by an “easy” direction in which the resistance is low, and a “hard” direction in which the resistance is high, is believed to be due to the formation of a spatially inhomogeneous “striped” electronic phase, though the precise nature of this phase and the physical mechanism that stabilizes it, is still unknown.

The report by Pan, W. *et al.* (page 132) summarizes experiments performed at the NHMFL on high quality GaAs/$Ga_{1-x}Al_xAs$ samples studying the effect of a tilted magnetic field on these exotic anisotropic states. The experiments showed very interesting behavior: Depending on the tilt direction, the easy direction and the hard direction remain either in the same place or trade places with increasing in-plane field. These results appear to indicate that the stripes tend to align themselves with the in-plane field. Even more surprising, the ν = 5/2 and 7/2 states, which do not show *any* initial in-plane anisotropy (in fact, they are incompressible quantum Hall states in the absence of an in-plane field), become highly anisotropic under tilt, similar to the ν = 9/2 and ν = 11/2 states. These experimental findings promise to help choose among the competing theoretical explanations of these fascinating new states and to pinpoint the underlying mechanism.

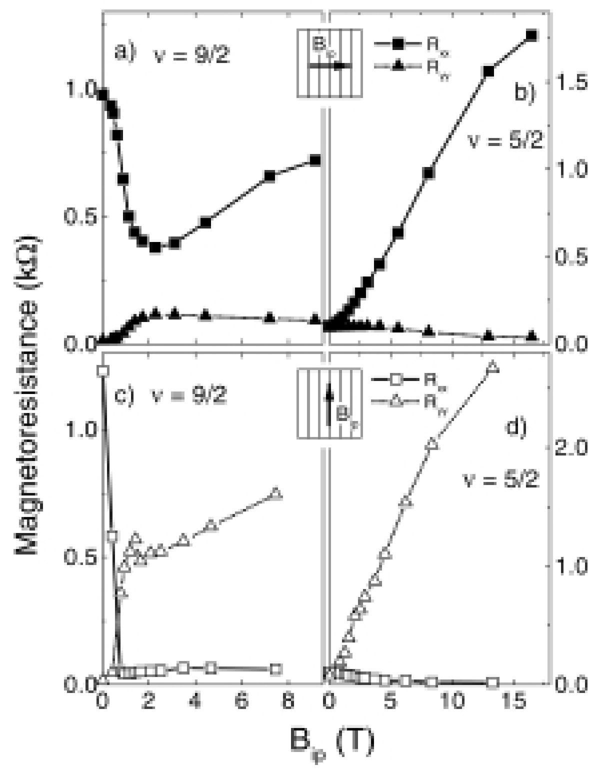

Figure 1. R_{xx} and R_{yy} as a function of in-plane magnetic field, B_{ip}, at filling fractions ν = 9/2 and 5/2 for two tilt directions.

Magnetism & Magnetic Materials

Among many hot issues in current research on magnetism, studies of magnetic phenomena and metal-insulator transitions in numerous oxide materials caused by doping present one of the most active directions. On the theory side, it adds to our understanding how strong electron correlations may compete with lattice effects and band conduction. On the other side, the materials under investigation present important potential for new applications. Such are the puzzling magnetic and transport properties of some ruthenates (Ca_2RuO_4 and $Ca_3Ru_2O_7$, Cao, G. *et al*. page 145) doped by La in the dilute limit. Ca_2RuO_4 seems to be of special interest, for its isostructural counterpart, Sr_2RuO_4, presents the only known p-wave superconductor so far.

Another example of new physics and very promising properties is provided by pseudocubic manganites, $A_{1-x}B_xMnO_3$, doped by substitutions of divalent atoms. It turns out that an exciting interplay of magnetic, transport, and structural transitions takes place at concentrations close to x = .5. For $Nd_{1/2}Sr_{1/2}MnO_3$ it is known that a highly resistive charge-ordered (CO) state can be melted by applying unexpectedly low (of the order ten teslas) magnetic fields into a ferromagnetic and conducting state. In experiments by Jung, J. H. *et al*. (page 151) the optical conductivity, "sigma(omega)", has been carefully measured to investigate the evolution of conductivity from the insulating to a metal behavior at low temperature with the field increase. In Figure 2, formation of a Drude-like peak is clearly seen together with redistribution of the spectral weight near 1 eV and 2.5 eV—features that seem to be due to localized carriers, possibly polarons.

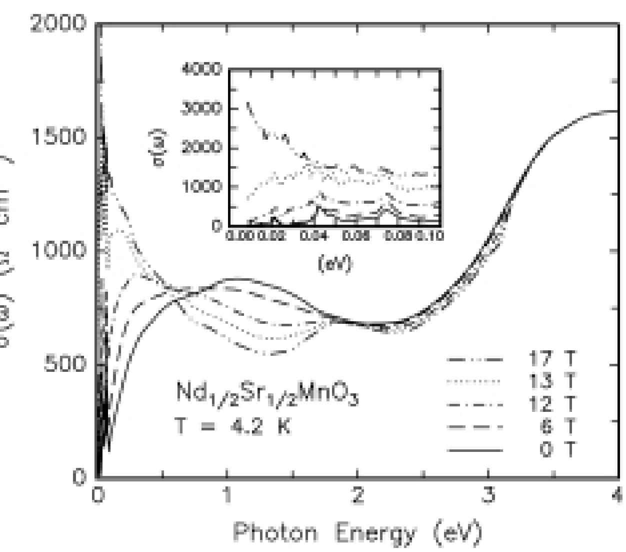

Figure 2. H-dependent $\sigma(\omega)$ of $Nd_{1/2}Sr_{1/2}MnO_3$. In the inset, $\sigma(\omega)$ below 0.1 eV are shown.

Other Condensed Matter

There are a number of novel, new experimental initiatives that users bring to the high magnetic field regime. High field NMR, well above 20 T, continues to be a frontier activity, as several papers in both organic conductor (Clark, W. G. *et al*. page 166) and glassy systems (Martin, S. W. *et al*. page 169) show. Similarly, access to high fields has produced renewed activity in the area of transport in elemental metals (Marchenkov, V. V. *et al*. page 168 and Li, Y. *et al*. page 168).

Of particular note is the use of high fields, and in particular the wide bore (195 mm) 20 T resistive magnet for magnetic alignment, materials processing, and magnetic force experiments. Walters, D. A. *et al.* (page 170) have studied the alignment of carbon nanotubes optically, and found that at 19 T the alignment energy is almost 30 times that of the room temperature thermal energy. They also produced a highly ordered thin film ribbon made of carbon nanotubes by magnetic alignment. The group of Brooks, J. *et al*. (page 165) has used the low gravity (magnetic levitation) effect to explore new forms of granular material. Unlike traditional "sand pile" studies of granular materials, particles in magnetic levitation have a finite effective temperature and can approach equilibrium configurations from disordered initial states. Also, unlike space shuttle studies, the magnetic field gradient produces a weak confining potential for suspended particle systems.

Magnetic Resonance Techniques

Research programs at the NHMFL continue to extend the upper limit of applied magnetic field in magnetic resonance techniques. Using the 25 T resistive Keck magnet, researchers have obtained GHz high resolution ^{1}H solution NMR spectra, Lin, Y. Y. *et al.* (page 182), high speed MAS solid state NMR spectra, and MAS NMR spectra of very low gamma nuclei, Fu, R. *et al.* (page 180). Using this same magnet, the highest field FT-ICR spectra to data have been recorded, Shi, S. D. H. *et al*. (page 186). Advances in radio-frequency coil technology, Fitzsimmons, J. *et al.* (page 177), and in pulse-sequence design for magnetic resonance imaging of large objects very high fields, Yang, Q. X. *et al.* (page 193), have also been made. Advances in electron magnetic resonance instrumentation, Yang, Q. X. *et al.* (page 193) should permit higher sensitivity with more precise phase control than previously attainable.

Engineering Materials

The construction and operation of high field/high performance magnets places a premium on engineering materials. Magnet designers are continuously searching for new materials better suited for the rigorous demands within high performance magnets. It is extremely rare for an engineering application to require such absolute specifications of strength, stiffness, ductility, fatigue life, and electrical and thermal properties. The development of new materials and the careful characterization of the material properties play a role of utmost importance with respect to the successful deployment of new magnets. The Engineering Materials research reports show a balance between the development of new materials and the characterization techniques used to measure the properties of new and commercial materials. Pulse and resistive magnets have the traditional need for conductors with high strength and high electrical conductivity. The challenge here is to develop new materials using innovative techniques such as the cryogenic deformation process described by Walsh, R. *et. al.* (page 198). In another case, careful tests have been performed where the conductor is fatigued through a stress regime dictated by the magnet operation mode. External reinforcement and prestress conditions create a shift of the fatigue stress regime that allows designers to take advantage of the extended fatigue life of a commercially available conductor (Han, K. *et al.* page 195).

Magnet Technology

With completion of many of the required resistive magnets for the NHMFL, attention is now being directed toward improved performance, increased reliability, and a wider range of field parameter space. Three research reports from the resistive magnet group illustrate this new direction (pages 199, 200, 201). Improved field homogeneity is allowing new kinds of measurements (for example, condensed matter NMR and EMR) in resistive magnets. According to analysis, ferroshimming should make possible uniformity levels of 1 ppm over 10 mm diameter in the Keck magnet. This level of uniformity is roughly two orders of magnitude higher than is achievable in conventional Bitter magnets. Similarly, axisymetric ferroshims can increase homogeneity in conventional Bitter coils by a factor of four. A second area of interest is to develop magnets with large uniform force regions (BdB/dz = constant) for levitation experiments. Two approaches to this problem are also reported. In high field standard bore resistive magnets, the uniformity of a constant force region can be increased by introducing an axisymetric ferroshim. In a separate report, it is also shown how the introduction of a small insert coil in the bore of the 20 T big bore (200 mm) resistive magnet can raise the levitation force above 1400 T^2/m, which is required to levitate water. Such a system would be the largest levitation experimental facility anywhere.

Cryogenics

Liquid helium fluid dynamics continues to be a major focus area for cryogenics research. This work is particularly beneficial to the large cryogenic installations such as for particle accelerator facilities. The study of flow in horizontal two phase He II/vapor is an excellent example (page 214). This work extends previous investigations of the combined roles of forced convection in the liquid/vapor mixture and counterflow heat transfer in the He II, by separately identifying the friction mechanisms in the liquid and vapor. To show future direction for the He II fluid dynamics studies, a proof of principle experiment was performed to demonstrate neutral density particle seeding in bulk He II. Previous reports of solid hydrogen particle seeding in liquid helium have yielded qualitative (and in some cases) quantitative information on the flow fields that exist in turbulent He II. The present work extends these investigations to develop a method of injecting particles into a channel contained flow field. The purpose is ultimately to apply quantitative particle imaging techniques to He II transport studies.